NASA TECHNICAL TRANSLATION NASA TT F-16,333

PRELIMINARY RESULTS OF RESEARCH CONDUCTED ABOARD THE SOVIET MARS-4, MARS-5, MARS-6, AND MARS-7 PLANETARY PROBES

V.I. Moroz

Translation of "Predvaritel'nyye rezul'taty issledovaniy, provedennykh na sovetskikh avtomaticheskikh stantsiyakh 'Mars-4', 'Mars-5', 'Mars-6', i 'Mars-7'," Kosmicheskiye Issledovaniya, Vol. 13, No. 1, January-February 1975, pp. 3-8

(NASA-TT-F-16333) PRELIMINARY RESULTS OF RESEARCH CONDUCTED ABOARD THE SOVIET MARS-4, MARS-5, MARS-6, AND MARS-7 PLANETARY PROBES (Kanner (Leo) Associates) 10 p HC $3.25 CSCL 03B G3/91

N75-24615

Unclas 21692

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C. 20546 MAY 1975

STANDARD TITLE PAGE

1. Report No. NASA TT F-16,333	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle: PRELIMINARY RESULTS OF RESEARCH CONDUCTED ABOARD THE SOVIET MARS-4, MARS-5, MARS-6, AND MARS-7 PLANETARY PROBES		5. Report Date: May 1975 6. Performing Organization Code
7. Author(s): V.I. Moroz		8. Performing Organization Report No. 10. Work Unit No.
9. Performing Organization Name and Address: Leo Kanner Associates, Redwood City, California 94063		11. Contract or Grant No.: NASw-2481 13. Type of Report and Period Covered: Translation
12. Sponsoring Agency Name and Address: National Aeronautics and Space Administration, Washington, D.C. 20546		14. Sponsoring Agency Code

15. Supplementary Notes:

Translation of "Predvaritel'nyye rezul'taty issledovaniy, provedennykh na sovetskikh avtomaticheskikh stantsiyakh 'Mars-4', 'Mars-5', 'Mars-6' i 'Mars-7'," Kosmicheskiye Issledovaniya, Vol. 13, No. 1, January-February 1975 pp. 3-8

16. Abstract: This is an introductory paper for the entire issue of the journal. It briefly reviews each of the 20 other papers and summarizes studies performed with the planetary probes Mars-4 to Mars-7. This probe group is regarded as a joint expedition that may provide the optimum combination of detailed investigation at a particular point on the planet's surface (from the descent module) with more general indirect studies from orbiting probes. The arrival schedule of the planetary probes and the sequence of actual events is described, and the orbital parameters of the orbiting Mars-5 probe are presented, as well as planet surface coordinates of the Mars-6 descent module. Two maps indicate the tracks of the probe instrumentation optical axis on the planet's surface. This word -- the "track" -- is used for this purpose throughout all papers.

17. Key Words (Selected by Author(s))	18. Distribution Statement: Unclassified-Unlimited			
19. Security Classif. (of this report): Unclassified	20. Security Classif. (of this page): Unclassified	21. No. of Pages: 10	22. Price	

NASA-HQ

PRELIMINARY RESULTS OF RESEARCH CONDUCTED ABOARD THE SOVIET MARS-4, MARS-5, MARS-6, AND MARS-& PLANETARY PROBES

V.I. Moroz

Investigations of radiation, reflected solar and thermal radiation, in different spectral regions by astrophysical methods until recently have been the only source of information on the physical characteristics of the atmosphere and surface of other planets. Orbital spacecraft substantially expanded the capabilities of astrophysical methods, since they made it possible to sharply reduce the distance to the object of the study and to improve the spatial resolution by tens and hundreds of times compared to the resolution that can be provided by the largest ground-based telescopes. Also, interference from the Earth's atmosphere was entirely removed and the parts of the planet which cannot be seen from Earth became accessible to study. /3*

Astrophysical methods of investigating planets based on their radiation characteristics with instruments installed on board orbital craft, and direct studies on board descent modules mutually supplement each other. A descent module can conduct detailed direct investigations at one point on the planet's surface, while an orbital craft can give more indirect results, but on the other hand results that extend over considerable areas and capable of embracing the entire planet. The optimum lies in the rational combination of both methods. The idea of this optimal combination was embodied in the expedition arriving at Mars in February-March 1974 and consisting of the four spacecraft: Mars-4, Mars-5, Mars-6, and Mars-7.

The first to reach the planet was Mars-4 (10 February 1974), arriving at a distance of 2200 km from its surface and taking

* Numbers in the margin indicate pagination in the foreign text.

photographs from a flyby trajectory. The second to arrive was Mars-5 (12 February), which was inserted into the orbit of an artificial satellite of the planet. The orbit had the following main parameters:

osculation period	$T = 24^h52^m50^s$
inclination	$i = 35°20'$
semimajor axis	$a = 20{,}570$ km
eccentricity	$e = 0.74974$
distance at pericenter to planet's center	$r_\pi = 5150$ km
distance at apocenter to planet's center	$r_a = 35{,}950$ km

The orbit was selected so that Mars-5 traversed during the sunlit time of the Martian days over a region selected for the landing of the descent modules that were carried by Mars-6 and Mars-7. Mars-7 approached the planet first (9 March), but its descent module, after a operating malfunction of one of the on-board systems arrived at the altitude of 1300 km above the planetary surface and did not execute a landing. On Mars-6 the operation of insertion of the descent module into a descent trajectory proceeded flawlessly, and on 12 March it descended to the surface of the planet in the region with coordinates $\phi = -24°$, $\lambda = 20°$.

In the nomenclature of the International Astronomical Union, this region is called Pyrrhae Region. For the first time in man's history, direct investigations of the Martian atmosphere were made. The studies of the atmospheric composition (a group headed by V.G. Istomin) showed that the Martian atmosphere contains inert gases in considerable quantities (35 ± 15%). Most probably, this is argon. This amount of argon means that the mean rate of gas evolution on Mars is comparable with the terrestrial rate, and the lower density of the Martian atmosphere is accounted /4

for most likely by the fact that most of the Martian atmosphere was condensed at the polar caps. In turn, this confirms the hypotheses suggesting that in the geologically not-distant past the atmosphere on Mars was much denser than today and that open bodies of water existed on the planetary surface.

On board the descent module, measurements were taken of the pressure, temperature, and altitude along the descent trajectory. These measurements covered the altitude region 0-20 km. In addition, to estimate the main atmospheric parameters, data obtained with accelerometers and measurements of the relative Doppler velocity along the descent module-orbital module line were resorted to. An combined analysis of all the data (a study done by a large group of authors, including V.S. Abduyevskiy, M.Ya. Marov, V.V. Kerzhanovich, and M.K. Rozhdestvenskiy) showed that all the data can be accounted for assuming the following atmospheric characteristics:

pressure at surface	6 mbar
temperature of atmosphere at surface	230°K
temperature gradient in tropopause	2.5°K/km
tropopause altitude	25-30 km
temperature of isothermal stratosphere	150-160°K

This model is in close agreement with the concepts of the Martian atmosphere obtained earlier through analysis of the radiation characteristics of the planet. The pressures in the Pyrrhae Region were measured from the Mars-5 orbital craft from the equivalent CO_2 bandwidths (L.V. Ksanfomaliti and V.I. Moroz), and the results agreed closely with direct measurements.

On board the orbital craft, two experiments on the chemical composition of the atmosphere were conducted. One was to measure the content of water vapor in the atmosphere from the intensity

of the 1.38 μm absorption band (V.I. Moroz and A.E. Nadzhip). It showed that in some regions of Mars the H_2O content can be as high as 100 μm of precipitable water, much more than was observed 2 years ago during this season with Mars-3. Also, it turned out that in the regions only a few hundred kilometers from each other, the H_2O content can differ by three to four times.

The second experiment measuring the minor constituents of the Martian atmosphere involved a photometer operating in the ozone band λ 2600 Å (V.A. Krasnopol'skiy et al.). The American Mariner stations earlier disclosed ozone fixed in the solid matter of the polar caps, but the question of whether it is present in the atmosphere remained open. The experiment on board Mars-5 reliably showed the presence of small amounts of ozone in the atmosphere. The altitude of the ozone layer was ~20 km. This result is important to understanding photochemical processes in the planetary atmosphere.

Two experiments on radio-occultation of the atmosphere, single-frequency (M.A. Kolosov et al.) and two-frequency (M.V. Vasil'yev et al.), yielded estimates of pressure in the lower atmosphere from the refraction phase shift, and also a profile of the electron concentration in the ionosphere. For the first time the ionosphere was investigated on the night side of the planet, where earlier here only the upper limit of the electron concentration was known.

Detailed data on the temperatures in the upper atmosphere of the planet and the structure of its exosphere were obtained through measurements of the intensity of the resonance glow of the L_α line (group lead by V.G. Kurt, with the participation of the French scientists J. Blamont et al.).

A large series of experiments dealt with the Martian surface. The planet was photographed with phototelevision cameras (PTC) of

different types (A.S. Selivanov et al.). There were about 60 photographs obtained by the Mars-4 and Mars-5 craft. Many of these were of high quality. They covered the region shown in Figs. 1 and 2. It was essential that Mariner-9 photograph this region during a period of a dust storm and could not here provide as high a photographic quality. Two cameras were used, a short- /7
focal length camera with resolution of about 1 km near the pericenter, and a long-focal length camera with a resolution of about 100 m. In addition, images were obtained with scanning photoelectric photometers.

The photographs taken were studied by geologists (see article of K.N. Florenskiy et al.), and they were also analyzed photogrammetrically (B.V. Nepoklonov et al.). Several photographs showed traces of water erosion, whose age was cautiously estimated as less than one billion years. This is independent support for the hypothesis of fluctuations in the density of the Martian atmosphere.

The study of the properties of the surface and soil from their radiation characteristics was conducted over a wide spectral region, beginning from radio waves and ending in gamma-radiation.

Instruments for these measurements were hard-mounted to the hull of the automatic interplanetary station [AIS] and they were oriented in a constant direction during measurements usually by means of the solar-star orientation system of the AIS. Photometers for H_2O and ozone were also oriented. With approach to the pericenter, the instruments were switched on several minutes before transiting the limb by a special optimal sensor. The optimal axes transited the planet usually along a line close to a great circle, and the transit from limb to limb took ~30 min. The terminator was transited 22 min past the sunlit limb. In the following, we will call the trace of the optical axis on the planetary surface the measurement track. From a preliminary

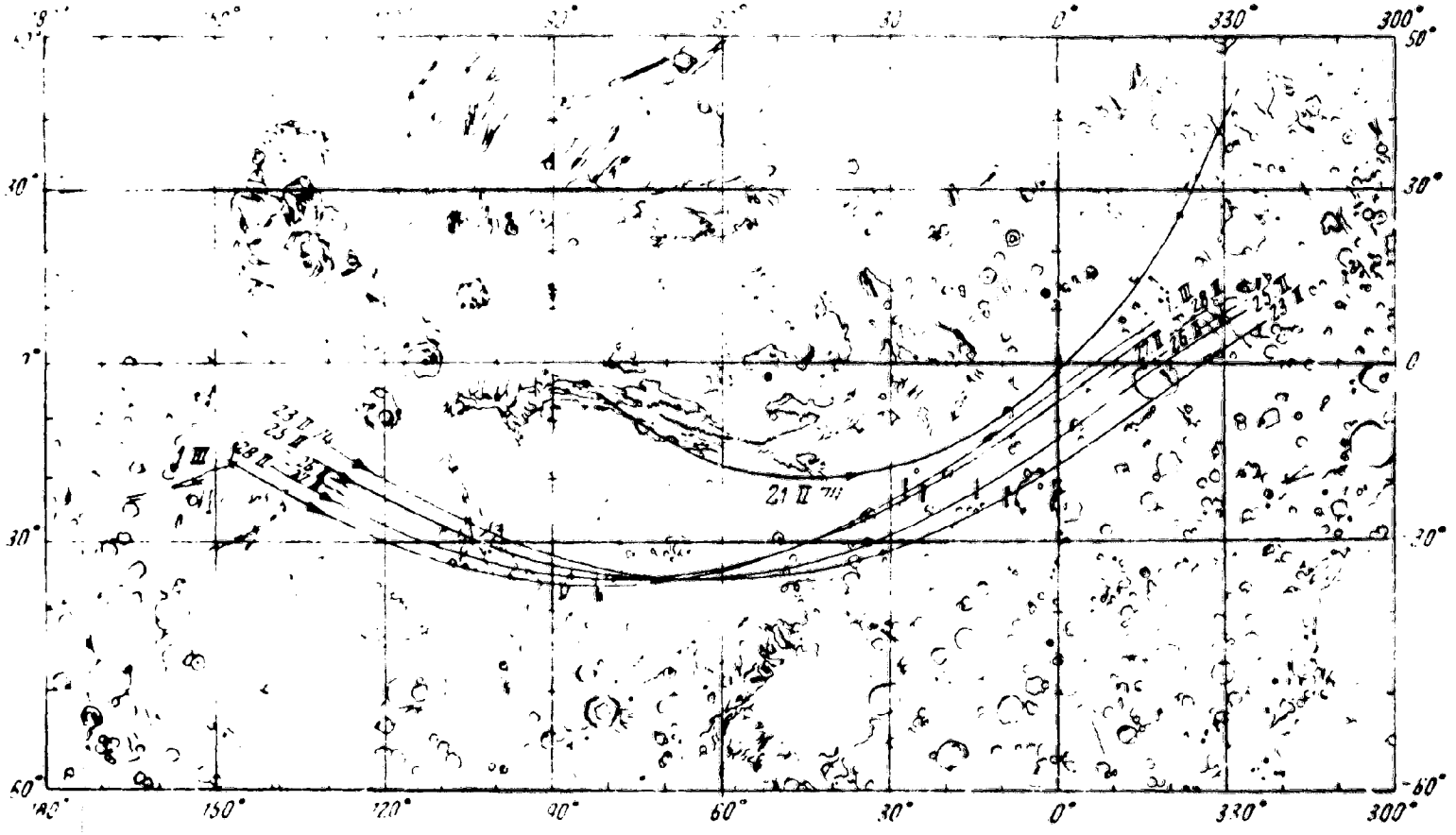
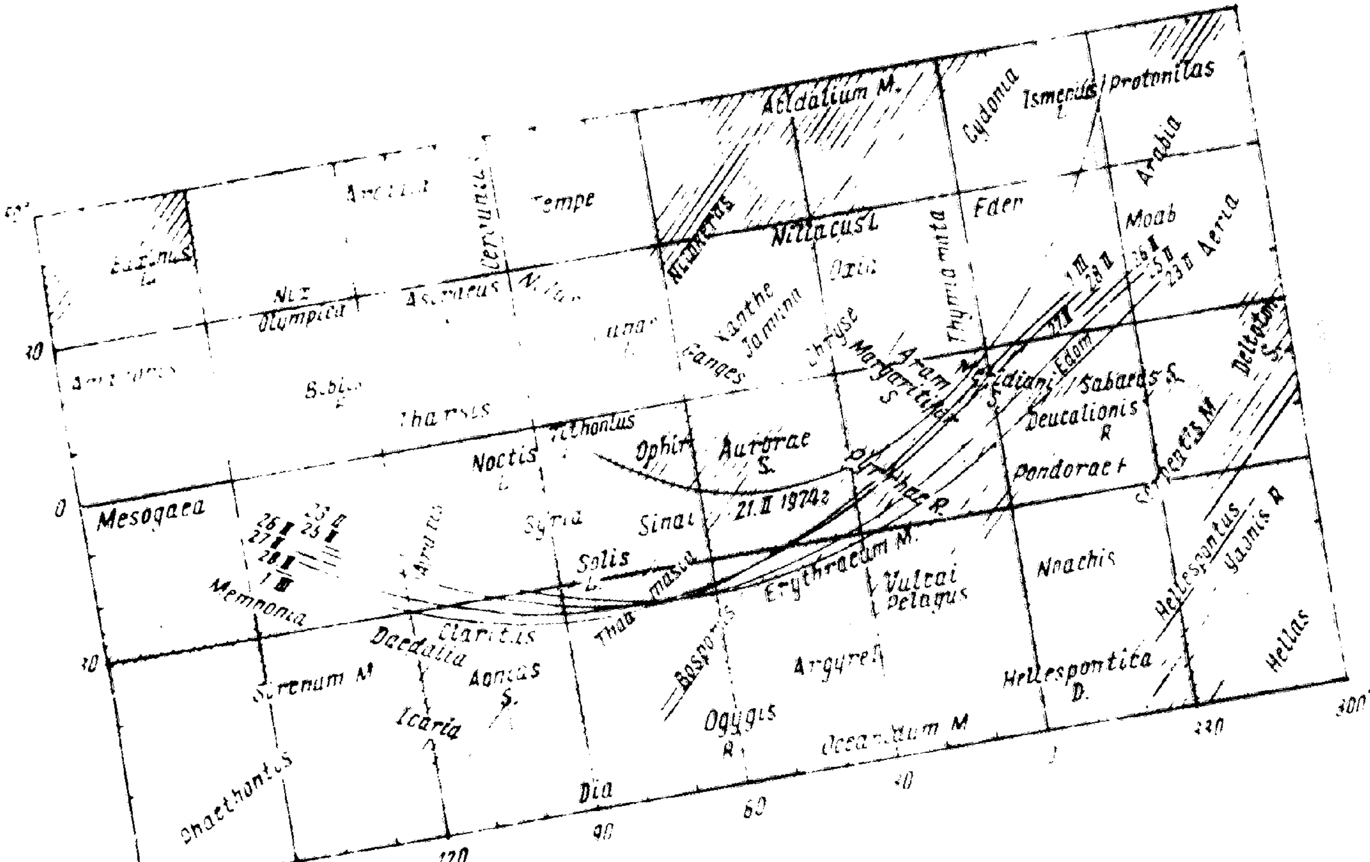


Fig. 1


Acidalium M.
Cydonia
Ismenius L.
Protonilas
Arabia
Tempe
Niliacus L.
Oxia
Eden
Moab
Aerea
Thymiamata
Nix Olympica
Xanthe
Chryse
Ganges
Margaritifer S.
Aram
Meridiani S.
Edom
Sabaeus S.
Deltoton S.
Deucalionis R.
Pandorae F.
Serpentis M.
Tharsis
Tithonius
Noctis L.
Ophir
Aurorae S.
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Mesogaea
Syria
Sinai
Solis L.
Thaumasia
Erythraeum M.
Vulcai Pelagus
Noachis
Hellespontus
Yaonis R.
Memnonia
Claritas
Daedalia
Bosporus
Argyre
Hellespontica D.
Hellas
Sirenum M.
Aonius S.
Icaria
Ogygis R.
Phaethontis
Dia
0
30
60
90
120
330
300°
60°

Fig. 2

estimate, the accuracy with which the measurement track was determined is 1-2° in terms of areographic coordinates.

Figs. 1 and 2 show the measurement tracks of the orbital craft Mars-5 from 21 February to 1 March for all instruments oriented parallel to the PTC.

The tracks of 23 February-1 March passed through the regions Araxes and Claritas, south of Solis Lacus (tangent along the southern side), and then across Thaumasia and Mare Erythraeum, and ending in Pyrrhae, where the descent module Mars-6 landed. The tracks were displaced longitudinally approximately 3° per day, while they nearly coincided along their central portions, which made it possible to carry out mutual monitoring of the measurements along different trajectories. The 21 February track lay north of the rest and had a different shape, since it was obtained when additional angles of rotation were present. A total of seven fully valuable measurement sessions were held and results were obtained for seven tracks.

One of the instruments, the infrared radiometer (L.V. Ksanfomaliti and V.I. Moroz), measured the soil brightness temperature in the 8-26 μm range. These measurements showed that the thermal inertia of the soil is in the range 0.004-0.009 cal·$\cdot deg^{-1}\cdot cm^{-2}\cdot sec^{-1/2}$. Hence we can estimate the characteristic size of soil grains -- from 0.1 to 0.5 mm.

On the other hand, photometric and polarimetric measurements showed that these grains have a microstructure of finer scale (of the order of a micron). Photometry of the planet in the 0.3-0.8 μm range was conducted with several photoelectric instruments (L.V. Ksanfomaliti). Measurements with polarimeters were conducted in this same range (L.V. Ksanfomaliti and V.I. Moroz, and A. Dolfuss, France). Photometric and polarimetric measurements from the spacecraft are valuable not only because they

provide high spatial resolution, but also ensure that Mars can be observed at phase angles inaccesssible from Earth.

The radio emission of the planet at the wavelength 3.4 cm was measured with a radio telescope (a collective of authors made up of A.Ye. Basharinov, N.N. Krupeino, A.D. Kuz'min, V.S. Troitskiy et al.). These measurements yielded data on temperature at a large depth (several tens of centimeters) as well as estimates of the dielectric constant. The dielectric constant depends on solar density and, thus, the measurements of radio emission enable us to arrive at an idea of density, and for values at a fairly significant depth below the surface.

The composition of the soil and its structure determine the reflectivity of the planet in the 0.3-4 μm range. The long-wave section of this interval was investigated with an infrared spectrophotometer (V.I. Moroz and N.A. Parfent'yev). Several hundreds of spectra were obtained in the 2-5 μm range. The presence of a water of crystallization band at about 3.2 μm was the most characteristic detail of these spectra. /8

A special instrument, a CO_2-altimeter (L.V. Ksanfomaliti and V.I. Moroz), measured the equivalent CO_2 bandwidths at about 2 μm. From them the profiles of pressure and altitude along the measurement tracks were determined. In the western part of the tracks there was a high region with the characteristic pressure 3-4 mbar, while in the eastern part -- 5-6 mbar. The tracks intersected two ridges with altitudes to 2-10 km above the reference level (6.1 mbar).

The gamma-spectrometer (Yu.A. Surkov, O.P. Shcheglov et al.) on Mars-5 yielded spectra of the gamma-radiation of the Martian rocks, from which an idea of their characteristic composition may be obtained.

One group of experiments dealt with the interplanetary plasma and the magnetic field in the vicinity of Mars.

Measurements of the magnetic field (Sh.Sh. Dolginov et al.) and the interplanetary plasma (K.I. Gringauz et al.) demonstrated new serious arguments in favor of the existence of the planet's intrinsic magnetic field. Studies of the plasma in interplanetary space were also conducted by the O.L. Vaysberg group. This same group measured the electrical fields.

The two last experiments that remain to be mentioned involve study of the Sun. This was the measurements of fluxes of solar cosmic rays (S.N. Vernov et al.) and investigation of solar radio emission in the meter band by simultaneous observation from a spacecraft and from Earth (Ye.M. Vasil'yev et al., Steinberg et al., France). The results of the first of these showed interesting features in the behavior of solar cosmic rays during flare periods.

Summing up, it can be concluded that the last expedition to Mars brought much new interesting data to science. Not all that was planned was done, however a great many fundamentally new results were obtained. Processing of the measurements of most experiments has just begun, and there is the certainty that subsequently the results presented here will be substantially supplemented. Unfortunately, not all the articles are included in this collection (B.V. Nepoklonov et al., A.Ye. Basharinov et al.; Yu.A. Surkov et al.; and Ye.M. Vasil'yev, Steinberg et al.) and will be published later.